

A recruitment manoeuvre performed after endotracheal suction does not increase dynamic compliance in ventilated paediatric patients: a randomised controlled trial

Brenda Morrow¹, Merle Futter¹ and Andrew Argent^{1,2}

¹University of Cape Town ²Red Cross War Memorial Children's Hospital
South Africa

Question: Does a recruitment manoeuvre after suctioning have any immediate or short-term effect on ventilation and gas exchange in mechanically-ventilated paediatric patients? **Design:** Randomised controlled trial with concealed allocation, assessor blinding, and intention-to-treat analysis. **Participants:** Forty-eight paediatric patients with heterogeneous lung pathology. Fourteen patients were subsequently excluded from analysis due to large leaks around the endotracheal tube. **Intervention:** The experimental group received a single standardised suctioning procedure followed five minutes later by a standardised recruitment manoeuvre. The control group received only the single suctioning procedure. **Outcome measures:** Measurements of ventilation (dynamic lung compliance, expiratory airway resistance, mechanical and spontaneous expired tidal volume, respiratory rate) and gas exchange (transcutaneous oxygen saturation) were recorded, on three occasions before and on two occasions after the recruitment manoeuvre, using a respiratory profile monitor. **Results:** There was no difference between the experimental and the control group in dynamic compliance, expired airway resistance, or oxygen saturation either immediately after the recruitment manoeuvre, or after 25 minutes. The experimental group decreased mechanical expired tidal volume by 0.3 ml/kg (95% CI 0.1 to 0.6), increased spontaneous expired tidal volume by 0.3 ml/kg (95% CI 0.0 to 0.6), and increased total respiratory rate by 3 bpm (95% CI 1 to 4) immediately after the recruitment manoeuvre compared with the control group, but these differences disappeared after 25 minutes. **Conclusion:** There is insufficient evidence to support performing recruitment manoeuvres after suctioning infants and children. [Morrow B, Futter M, Argent A (2007) A recruitment manoeuvre performed after endotracheal suction does not increase dynamic compliance in ventilated paediatric patients: a randomised controlled trial. *Australian Journal of Physiotherapy* 53: 163–169]

Key words: Recruitment Manoeuvre; Respiratory Mechanics, Suction; Pediatric, Randomized Controlled Trial

Introduction

Intubated patients need regular endotracheal suctioning to remove pulmonary secretions and maintain a patent airway. During open suctioning, where the patient is disconnected from the ventilator before suctioning the endotracheal tube, the decrease in airway pressure causes loss of lung volume which is exacerbated by applying the negative suction pressure (Maggiore et al 2003, Taskar et al 1997). This causes dynamic compliance to drop after suctioning (Brandstater and Muallem 1969, Hipenbecker and Guthrie 1981, Morrow et al 2006, Polacek and Guthrie 1981). The periodic derecruitment caused by suctioning could be harmful in patients with acute respiratory distress syndrome or acute lung injury (Taskar et al 1997), where optimising alveolar recruitment and maintaining lung volume is necessary in order to prevent lung injury (Amato et al 1998).

Recruitment manoeuvres have been suggested as a method of reversing suctioning-induced lung volume loss and improving arterial oxygenation, by reinflating the collapsed lung segments before resuming ventilation (Lindgren et al 2004, Matthews and Noviski 2001, Suh et al 2002). A recruitment manoeuvre is the application of a sustained inflation pressure to the lungs for a specific duration in order to return the lung to normal volumes and distribution of air (Matthews and Noviski, 2001). Dhyr et al (2003)

reported that a recruitment manoeuvre performed after open endotracheal suctioning was well tolerated and produced rapid recovery in end-expiratory lung volume, respiratory compliance, and arterial oxygenation in a small study in adults. Preceding suctioning with manual hyperinflation improved static lung compliance and airway resistance compared with suctioning alone in adults with ventilator-associated pneumonia (Choi and Jones 2005). The ARDS (acute respiratory distress syndrome) Clinical Trials Network (2003), however, found a variable response in oxygen saturation to recruitment manoeuvres in adults with acute respiratory distress syndrome: in some patients it decreased and in others it increased markedly. There was no difference in the change in respiratory system compliance between groups receiving recruitment manoeuvres or sham recruitment manoeuvres.

Although recruitment manoeuvres have been shown to be effective in animal models (Cakar et al 2000, Lu et al 2000, Rimensberger et al 1999, Russell et al 2002, Van der Kloot et al 2000) and in some human adult studies (Lapinsky et al 1999, Lim et al 2001, Richards et al 2001), it is inappropriate to extrapolate these results directly to the paediatric population because of anatomical and physiological differences which make infants and small children especially vulnerable to volu- or barotrauma. There are only two studies investigating recruitment manoeuvres in infants and children and they were carried out on normal

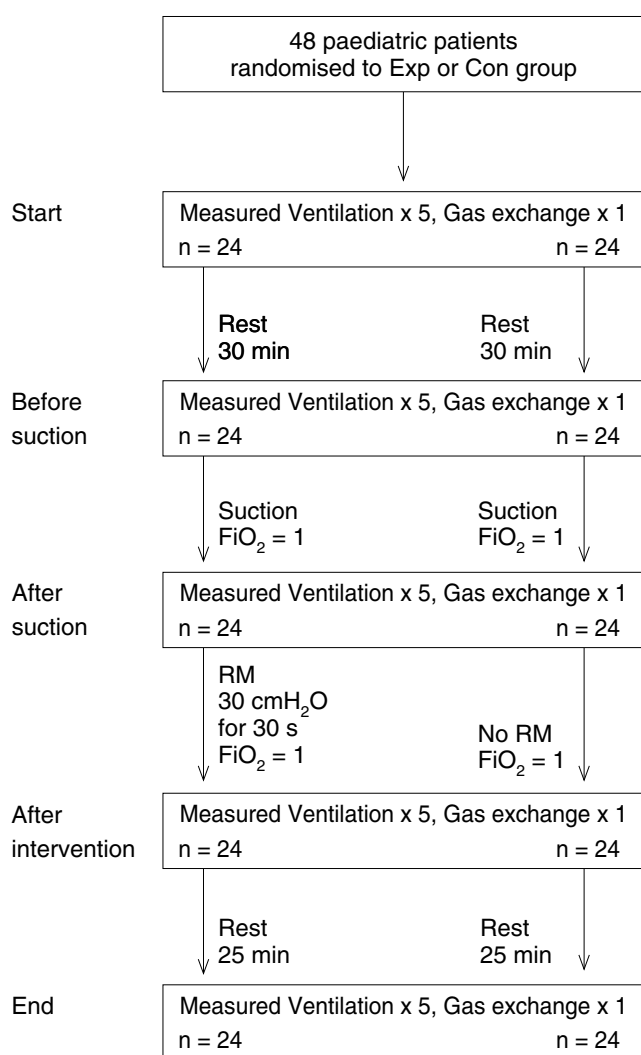


Figure 1. Design of and flow of participants through the trial. All participants completed the trial but seven participants in each group with endotracheal tube leaks > 20% were excluded from the analysis. Exp = experimental group, Con = control group, RM = recruitment manoeuvre

lungs rather than in patients with pulmonary disease, or following suctioning (Marcus et al 2002, Tusman et al 2003). Therefore, our research questions were:

1. Does a recruitment manoeuvre after suctioning have any immediate effect on ventilation and gas exchange in mechanically-ventilated, non-paralysed paediatric patients with pulmonary disease?
2. Does a recruitment manoeuvre after suctioning have any short-term (25 minutes) effect on ventilation and gas exchange in mechanically-ventilated, non-paralysed paediatric patients with pulmonary disease?

Method

Design

We conducted a prospective, randomised controlled trial (Figure 1). Mechanically-ventilated, paediatric patients were randomly assigned to receive a recruitment manoeuvre after suctioning or not by means of concealed, opaque

envelopes selected by independent physiotherapists. The same physiotherapists assigned codes to the groups and performed the suctioning and recruitment manoeuvre. Measures of ventilation and gas exchange were collected by a respiratory profile monitor before and after 30 minutes of rest, after suction, after the recruitment manoeuvre, and after 25 minutes of rest. The codes were revealed only once all data were analysed so that the person who performed the data analysis (first author) was blinded to group allocation. Ethical approval was obtained from the Human Research Ethics Committee of the University of Cape Town. Written, informed consent was obtained from the patients' legal guardians before data collection and the study was monitored by a Safety Monitoring Committee.

Participants

Participants were recruited from patients in the paediatric intensive care unit of Red Cross War Memorial Children's Hospital, a tertiary level academic hospital situated in Cape Town, South Africa. Patients were included in the study if they were being mechanically ventilated with endotracheal tubes ≤ 4 mm internal diameter and had primary or secondary pulmonary disease. Patients were excluded from the study if they had: any cardiac abnormality or disease, either congenital or acquired; raised intracranial pressure, or the potential to develop pathologically raised intracranial pressure (including patients with meningitis, post head injuries, intracranial tumours, hydrocephalus etc); haemodynamic instability for the preceding 24 hours (changes $\geq 20\%$ in mean arterial blood pressure, heart rate or SaO_2); an average baseline oxygen saturation of $< 85\%$; a pneumothorax, or a history of pneumothorax; coagulopathy, with a platelet count $< 100 \times 10^9 / \text{l}$; or were post thoracic surgery, or were premature or small for gestational age.

Age, gender, weight, medical condition, FiO_2 and ventilation settings, the morning arterial blood gas analysis, endotracheal tube internal diameter, patient position (prone or supine), and the number of days the patient had been mechanically ventilated were recorded.

Intervention

After 30 minutes of rest, for 30 seconds before a single-catheter insertion suctioning procedure (Morrow et al 2006), 100% oxygen was given and was decreased to pre-suction values again immediately after the recruitment manoeuvre. Apart from this, ventilation settings were constant during the measurement period. Participants did not receive additional sedation, muscle paralysis, or analgesia, and therefore could potentially breathe spontaneously between ventilator breaths. All participants received continuous morphine infusions as standard practice. Participants had been in the same position for more than an hour prior to the start of measurement, and were not moved for the duration of the measurement period.

Five minutes after suctioning, the experimental group received a recruitment manoeuvre comprising a single sustained inflation pressure of 30 cmH_2O applied for 30 seconds. The recruitment manoeuvre was performed manually by means of a one-litre anaesthetic bag, with 10 l/min gas flow of 100% oxygen, connected to a pressure manometer. The control group underwent suctioning, but did not receive a recruitment manoeuvre. Thereafter, the ventilator was immediately reconnected on its original settings. The procedure was terminated if there was a 20% change in mean arterial blood pressure; a decrease

Table 1. Characteristics of participants (n = 48).

	Included participants		Excluded participants	
	Exp (n = 17)	Con (n = 17)	Exp (n = 7)	Con (n = 7)
Characteristic, mean (SD)				
Age (mth)	5.7 (5.4)	6.8 (5.8)	7.4 (8.2)	3.4 (2.5)
Weight (kg)	5.5 (2.8)	5.1 (2.2)	5.7 (2.8)	5.2 (1.7)
Ventilated days	4.2 (5.1)	4.1 (3.8)	2.7 (3.3)	2.6 (2.4)
ETT size (mm ID)	3.5 (0.3)	3.4 (0.4)	3.4 (0.6)	3.2 (0.3)
FiO ₂	0.5 (0.2)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)
Respiratory rate (bpm)	26.9 (8.5)	21.7 (6.8)	20.3 (7.2)	22.7 (5.5)
PIP (cmH ₂ O)	23.4 (4.7)	22.3 (4.5)	25.1 (4.7)	23.1 (2.0)
PEEP (cmH ₂ O)	7.0 (2.6)	6.0 (2.5)	6.4 (2.5)	6.1 (2.7)
MAP (cmH ₂ O)	11.5 (3.5)	9.9 (3.0)	10.3 (4.0)	10.4 (2.5)
PaO ₂ /FiO ₂ (mmHg)	188 (128)	259 (188)	337 (288)	304 (191)
Condition, number (%)				
Pneumonia	16 (94)	15 (88)	5 (71)	7 (100)
Sepsis	1 (6)	3 (18)	1 (14)	2 (29)
Shocked gastroenteritis	1 (6)	2 (12)	0 (0)	2 (29)
Near drowning	1 (6)	0 (0)	1 (14)	0 (0)
Upper airway obstruction	1 (6)	0 (0)	1 (14)	0 (0)
Chemical pneumonitis	0 (0)	0 (0)	1 (14)	0 (0)
Positioned prone, number (%)	8 (47)	11 (65)	1 (14)	3 (43)

ETT = endotracheal tube, ID = internal diameter, FiO₂ = fraction of inspired oxygen, PIP = peak inspiratory pressure, PEEP = positive end-expiratory pressure, MAP = mean airway pressure

in oxygen saturation to < 80%; and/or any other cardiac arrhythmia, including brady- and tachycardia indicated by the continuous electrocardiographic, blood pressure, and pulse oximetry monitoring.

An inflation pressure of 30 cmH₂O was chosen for the recruitment manoeuvre as it was found to be safe and effective in one of the few paediatric studies of recruitment manoeuvres performed on children with normal lungs (Marcus et al 2002). The application of positive pressure was sustained for 30 seconds in accordance with animal model studies (Cakar et al 2000, Rimensberger et al 1999, Van der Kloot et al 2000). It was decided that a manual recruitment manoeuvre would be tested as opposed to changing ventilator settings, in order to minimise potential harm to the participant which could occur if the ventilator settings were not returned to pre-intervention settings after the procedure.

Outcome measures

Participants were connected to a respiratory mechanics monitor^(a) using neonatal flow sensors, which add < 1 ml deadspace, for 30 minutes before and 30 minutes after suctioning. This monitor has been validated as a sensitive and accurate tool in fully ventilated, paralysed paediatric patients (Main et al 2001). Measures of dynamic lung compliance from this respiratory mechanics monitor are highly repeatable in non-paralysed, ventilated paediatric patients who are able to breathe spontaneously between ventilator breaths (Morrow et al 2006). The coefficient of variation of dynamic compliance was small (< 5%) with no significant change following suctioning.

Dynamic compliance, expiratory airway resistance,

mechanical and spontaneous expired tidal volume, and respiratory rate were downloaded from the monitor. Expired tidal volume was used rather than inspired tidal volume to minimise errors due to endotracheal tube leak in children with uncuffed endotracheal tubes (Kuo et al 1996, Main et al 2001). The CO₂SMO Plus automatically averages breath-by-breath values over each minute. The mean of five of these readings at each measurement occasion were used for analysis. The measures were corrected for weight where applicable.

Data analysis

A power calculation conducted *a priori* indicated that 48 participants would provide 80% power at $\alpha = 0.05$ to detect a difference of 0.05 ml/cmH₂O/kg in change in dynamic compliance between the groups, based on the results of a previous study (Morrow et al 2006).

The baseline percentage leak around the endotracheal tube was calculated for each patient using the first five minutes' averaged values of inspired and expired mechanical tidal volume according to the equation:

$$\% \text{ Leak} = [(V_{ti}^{\text{mech}} - V_{te}^{\text{mech}}) / V_{ti}^{\text{mech}}] \times 100$$

(Main et al 2001).

Data were tested for normality using Kolmogorov-Smirnov and Lilliefors' tests. Where the residuals were normally distributed, two-way repeated measures ANOVA was used to assess differences in effect between groups. The majority of data were not normally distributed and therefore non-parametric statistical analyses were performed. Between-group independent variables were compared using the Mann-Whitney U test. Spearman's rank order correlation

Table 2. Groups, difference within groups, and difference between groups (95% CI) of all outcomes for the experimental group (n = 17) and the control group (n = 17).

Outcome	Groups										Difference between groups			
	Start		Before suction		After suction		After intervention		End		After intervention minus after suction		End minus after suction	
	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con
Ventilation														
Cdyn (ml/cmH ₂ O/kg), median (IQR)	0.5 (0.6)	0.6 (0.3)	0.5 (0.6)	0.6 (0.3)	0.5 (0.3)	0.6 (0.3)	0.6 (0.3)	0.6 (0.3)	0.5 (0.6)	0.6 (0.3)	0 (0.3)	0 (0.2)	0 (0.2)	0 (-0.1 to 0.1)
R _e (cmH ₂ O/l/s), median (IQR)	78.0 (49.3)	61.9 (69.3)	68.3 (56.4)	58.2 (79.1)	81.5 (67.4)	64.1 (66.3)	65.0 (54.3)	46.3 (67.3)	64.7 (64.5)	49.8 (73.9)	-6.0 (25.1)	-2.5 (39.8)	-3.9 (33.1)	-0.9 (26.9)
Vte ^{mech} (ml/kg), median (IQR)	5 (2.5)	7.1 (2.1)	5.9 (3.2)	7.3 (2.2)	5.7 (3.1)	6.9 (2.3)	5.6 (2.7)	7.7 (2.7)	6.4 (2.7)	7.4 (3.2)	0 (0.9)	0.5 (1.4)	0.4 (0.9)	0.2 (-0.4 to 0.6)
Vte ^{spont} (ml/kg), median (IQR)	2 (3.1)	2.6 (4.5)	2.2 (3.1)	2 (4.5)	2.4 (3.1)	2.6 (3.5)	2.5 (3.4)	2.2 (5.1)	2.4 (3.5)	2.5 (4.3)	0.1 (0.8)	0 (0.9)	0 (0.8)	0.25 (0.0 to 0.6)
Total RR (bpm), median (IQR)	43 (46)	48 (24)	46 (43)	42.00 (25)	49 (43)	47 (25)	53 (39)	44 (25)	45 (44)	43 (21)	1 (7)	-1 (5)	0 (9)	2 (0 to 6)
Gas exchange														
SaO ₂ (%), mean (SD)	92.6 (3.5)	95.5 (2.6)	96.2 (4.8)	97.1 (3.2)	95.8 (4.9)	97.9 (3.3)	97.5 (3.4)	98.7 (2.4)	96 (3.2)	95.4 (4.3)	1.7 (3.9)	0.8 (1.8)	-1.5 (2.9)	-2.8 (4.2)

Exp = experimental group, Con = control group, Cdyn = dynamic lung compliance, R_e = expiratory airway resistance, Vte^{mech} = mechanical expired tidal volume, Vte^{spont} = spontaneous expired tidal volume, RR = respiratory rate, SaO₂ = transcutaneous oxygen saturation

tests were used to assess relationships between participant characteristics, starting dynamic compliance, and the change in dynamic compliance in response to the recruitment manoeuvre.

Results

Flow of participants through the trial

Forty-eight participants were recruited over an 18-month period from May 2003 to the end of October 2004. They were all receiving conventional pressure-limited, time-cycled mechanical ventilation with constant through-flow of gas (allowing spontaneous non-triggered breaths). The characteristics of the participants, the condition for which they were admitted to the intensive care unit, and their position during the intervention are presented in Table 1.

Equal numbers were randomly assigned to intervention and control groups (Figure 1). The participant with inhalational burns was included in the analysis, as his chest was not burnt and constrictive dressings were therefore not applied. However, seven participants in each group were found to have endotracheal tube leaks $\geq 20\%$ and were excluded from subsequent analysis (Main et al 2001). The median leak for the remaining participants was small at 0.1% (IQR 13). Of the remaining 34 participants, eight (47%) in the control group were found to fulfil the criteria for acute respiratory distress syndrome with acute onset of respiratory disease, bilateral infiltrates on chest X-ray, $\text{PaO}_2/\text{FiO}_2 \leq 200$ mmHg, and no clinical evidence of left atrial hypertension (Bernard et al 1994). Four participants (24%) presented with acute lung injury with the same criteria as acute respiratory distress syndrome except for a $\text{PaO}_2/\text{FiO}_2$ of ≤ 300 mmHg (Bernard et al 1994). In the experimental group, 12 participants had acute respiratory distress syndrome (71%) and one participant acute lung injury (6%). In total, nearly two-thirds of the participants fulfilled the criteria for acute respiratory distress syndrome.

Compliance with trial method

The concealment of group allocation was successful, with unblinding occurring only after all data analysis was complete. Participants were analysed in the groups to which they were randomised. The approved protocol was followed for the duration of the study under observation of the Safety Monitoring Committee. No adverse events occurred during or after the recruitment manoeuvre in any participant. Heart rate and blood pressure remained stable during the recruitment manoeuvre for all participants and oxygen saturation remained $> 85\%$. No pneumothoraces occurred.

Effect of intervention

Group data for the five measurement occasions as well as within- and between-group data are presented in Table 2, while individual data for the five measurement occasions are presented in Table 3 (see eAddenda for Table 3). There was no difference between the experimental and the control group in dynamic compliance, expired airway resistance, or oxygen saturation either immediately after the study intervention, or after 25 minutes. Eight participants in the recruitment group and seven in the control group experienced an increase in dynamic compliance following the recruitment manoeuvre of $> 20\%$ ($p = 0.80$).

The experimental group decreased mechanical expired tidal volume by 0.3 ml/kg (95% CI 0.1 to 0.6, $p = 0.03$) immediately after the recruitment manoeuvre compared

with the control group. However, mechanical expired tidal volume subsequently increased in the experimental group so that after 25 minutes there was no difference between groups. The experimental group increased spontaneous expired tidal volume by 0.3 ml/kg (95% CI 0.0 to 0.6, $p = 0.04$) immediately after the study intervention compared with the control group. However, spontaneous expired tidal volume subsequently decreased in the experimental group so that after 25 minutes there was no difference between groups. The experimental group also increased total respiratory rate by 3 bpm (95% CI 1 to 4, $p < 0.001$) immediately after the study intervention compared with the control group but this difference also disappeared after 25 minutes.

There was no correlation between age, weight, starting dynamic compliance, $\text{PaO}_2/\text{FiO}_2$ and the change in dynamic compliance after the study intervention ($p > 0.10$ for all).

Discussion

This is the first study to investigate the effect of a recruitment manoeuvre after suctioning on ventilation and gas exchange in a representative group of stable, ventilated infants and children with variable lung disease. The severity of illness in these participants may have been greater than that seen in First World situations, due to the issues faced by a developing nation such as resource limitation and a population living in poor socioeconomic circumstances.

All participants with endotracheal tube leaks $\geq 20\%$ were excluded from the analysis with the resulting median leak being small. Thus, any recorded changes were unlikely to be artefactual (Main et al 2001). No complications of the recruitment manoeuvre were observed. Both the control and the experimental groups experienced an increase in dynamic compliance immediately after the study intervention. This change was not greater in the experimental group, indicating that the decrease in dynamic compliance from suctioning resolved spontaneously with unchanged ventilator settings, ie, that the recruitment manoeuvre was no more effective in improving dynamic compliance than replacing the ventilator alone.

This result was somewhat surprising. Given that the starting dynamic compliance was lower than the normal range (1.1 to 2.0 ml/cmH₂O/kg in healthy infants), it was expected that participants would respond positively to the recruitment manoeuvre. Also, in the experimental group, the lower starting mechanical expired tidal volume and lower $\text{PaO}_2/\text{FiO}_2$ requiring higher ventilatory pressures, respiratory rates and supplemental oxygen than those in the control group implied a greater potential for recruitment. However, this was not found to be the case.

These results are contrary to the findings of Dhyr et al (2003) in their study of recruitment manoeuvres performed after endotracheal suctioning in adults. They found that after suctioning with no recruitment manoeuvre, maximal respiratory compliance had not recovered after 25 minutes, whereas with the recruitment manoeuvre compliance was rapidly regained. Their study, however, differed in that the participants were adults who were deeply sedated during the procedures.

Despite the lack of discernible differences in the dynamic compliance after the recruitment manoeuvre, the change was variable, indicating that it may be worthwhile in certain circumstances. However, it was not possible to identify

these circumstances. The amount of change in dynamic compliance in response to a recruitment manoeuvre which would be clinically worthwhile is not yet known. In children and infants there is a balance between high chest wall and low pulmonary compliance related to underdeveloped lung parenchyma, small airway diameter, and small alveoli (Tusman et al 2003). Although collapsed alveoli require a high inspiratory pressure to expand, the optimal inflation pressure required to safely recruit alveoli in this group is not yet known.

There are several possible explanations as to why the recruitment manoeuvre did not result in a greater improvement in dynamic compliance in this study. There may have been insufficient power to detect a difference in dynamic compliance between the groups after excluding 14 participants with large endotracheal tube leaks. It is possible that the large number of drop-outs introduced bias, although starting parameters were very similar between these participants and those included in analysis and randomisation was maintained throughout. Participants may have been receiving optimal ventilation with appropriate positive airway pressure levels, thus reducing the potential for lung recruitment; or the brief discontinuation of positive airway pressure before and after applying the recruitment manoeuvre may have caused lung volume loss (Neumann et al 1998), negating any recruitment effect. On the other hand, the variability of positive airway pressures amongst participants may confound the response to the recruitment manoeuvre. The recruitment manoeuvre may have preferentially over-distended aerated alveolar units before expanding collapsed areas (La Place's Law) which would cause dynamic compliance to either remain unchanged or decrease (Foti et al 2000). Participants did not receive paralysing agents prior to the recruitment manoeuvre, in order to best approximate clinical practice. Therefore, a variable amount of motor activity occurred. Coughing, in particular, could rapidly reverse any effect of a recruitment manoeuvre (ARDS Clinical Trials Network 2003). The majority of participants had primary acute respiratory distress syndrome, mostly due to pneumonia. None had extrapulmonary or secondary acute respiratory distress syndrome related to sepsis or trauma which may respond more positively to the recruitment manoeuvre (Lim et al 2003, Pelosi et al 2003). The optimal pressure or duration of the recruitment manoeuvre may not have been achieved.

It has been observed that prone positioning removes pressure and recruits atelectatic dorsal regions of the lung, limits anterior chest wall movement, and reduces the effects of abdominal pressure on the thoracic cavity. These effects have been found to promote more uniform alveolar ventilation (Barbas 2003; Matthews and Noviski 2001), reduce intrapulmonary shunt, and improve ventilation/perfusion matching and oxygenation (Marraro 2003, Pelosi et al 1998). Therefore, in clinical practice, turning patients prone prior to the recruitment manoeuvre may improve its efficacy.

Respiratory rate increased immediately after the recruitment manoeuvre in the experimental group compared with the control group. This increase in respiratory rate may be compensatory due to cessation of ventilation during the recruitment manoeuvre or due to increased agitation of the participants during the recruitment manoeuvre.

Although acute changes in SaO_2 did not occur after the study intervention; post-hoc analysis revealed that the

experimental group increased SaO_2 by a mean of 3.4% (CI 0.62 to 6.3, $p = 0.04$) from the start to the end of the study period as compared to the control group. Cardiac output, which may influence SaO_2 , was not found to change after recruitment manoeuvre in adults (Villagra et al 2002). If this holds true for paediatrics, the improved oxygenation was probably caused by recruiting perfused, nonventilated alveoli with a subsequent reduction in intrapulmonary shunting (Maggiore et al 2001).

Similarly, post-hoc analysis showed that the experimental group decreased expired airway resistance by $-8.8 \text{ cmH}_2\text{O/l/s}$ (CI -26.1 to 4.1 , $p = 0.06$) between the start and the end of the study period, compared with the control group. The difference between the two groups approached significance, with the possibility that this study was not sufficiently powered to detect a true statistical difference. The change in resistance may reflect opening of previously occluded bronchi or bronchioles during the recruitment manoeuvre (Young 1984). This, along with the improvement in SaO_2 , suggests that the recruitment manoeuvre may have been at least partly successful in recruiting alveoli.

In conclusion, performing a recruitment manoeuvre after endotracheal suctioning had no immediate or short term benefits on ventilation or gas exchange. Therefore, more information is needed from paediatric clinical studies before recruitment manoeuvres can be recommended in ventilated infants and children.

eAddenda: Table 3 available at www.physiotherapy.asn.au/AJP

Footnotes: ^(a) CO_2 SMO Plus! Model 8000 Respiratory Profile Monitor. Respironics, USA.

Acknowledgements: The authors gratefully acknowledge funding from the School of Child and Adolescent Health, Faculty of Health Sciences, University of Cape Town; and the Red Cross Children's Hospital Trust. Brenda Morrow is currently a Postdoctoral Research Fellow funded by the Medical Research Council of South Africa.

Correspondence: Dr Brenda Morrow, Division of Paediatric Critical Care and Children's Heart Disease, UCT School of Child and Adolescent Health, Red Cross War Memorial Children's Hospital, Klipfontein Road, Rondebosch 7700, Cape Town, South Africa. Email: brenda.morrow@uct.ac.za

References

- Amato MBP, Barbas CSV, Medeiros DM, Magaldi RB, Schettino GPP, Lorenzi-Filho G, Kairalla RA, Deheinzelin D, Munoz C, Oliveira R, Takagaki TY, Carvalho CRR (1998) Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome. *New England Journal of Medicine* 338: 347–354.
- ARDS Clinical Trials Network, National Heart, Lung and Blood Institute, National Institutes of Health (2003) Effects of recruitment maneuvers in patients with acute lung injury and acute respiratory distress syndrome ventilated with high positive end-expiratory pressure. *Critical Care Medicine* 31: 2592–2597.
- Barbas CSV (2003) Lung recruitment maneuvers in acute respiratory distress syndrome and facilitating resolution. *Critical Care Medicine* 31:S265–271.
- Bernard G, Artigas A, Brigham K, Carlet J, Falke K, Hudson L, Lamy M, LeGall J, Morris A, Spragg R (1994) The American-European consensus conference on ARDS. Definitions, mechanisms, relevant outcomes, and clinical trial coordination.

- American Journal of Respiratory and Critical Care Medicine* 149: 818–824.
- Brandstater B, Muallem M (1969) Atelectasis following tracheal suction in infants. *Anesthesiology* 31: 468–473.
- Cakar N, Van der Kloot T, Youngblood AM, Adams A, Nahum A (2000) Oxygenation response to a recruitment maneuver during supine and prone positions in an oleic acid-induced lung injury model. *American Journal of Respiratory and Critical Care Medicine* 161: 1949–1956.
- Choi JS, Jones AY (2005) Effects of manual hyperinflation and suctioning on respiratory mechanics in mechanically ventilated patients with ventilator-associated pneumonia. *Australian Journal of Physiotherapy* 51: 25–30.
- Cox RG, Ewen A, Bart BB (2001) The prone position is associated with a decrease in respiratory system compliance in healthy anaesthetised infants. *Paediatric Anaesthesia* 11: 291–296.
- Dyhr T, Bonde J, Larsson A (2003) Lung recruitment manoeuvres are effective in regaining lung volume and oxygenation after open endotracheal suctioning in acute respiratory distress syndrome. *Critical Care* 7: 55–62.
- Foti G, Cereda M, Sparacino ME, De Marchi L, Villa F, Pesenti A (2000) Effects of periodic lung recruitment maneuvers on gas exchange and respiratory mechanics in mechanically ventilated acute respiratory distress syndrome (ARDS) patients. *Intensive Care Medicine* 26: 501–507.
- Hippenbecker DL, Guthrie MM (1981) The effects of negative pressure generated during endotracheal suctioning on lung volumes and pulmonary compliance. *American Review of Respiratory Disease* 123: (Suppl) 120.
- Kuo C, Gerhardt T, Bolivar J, Claure N, Bancalari E (1996) Effect of leak around the endotracheal tube on measurements of pulmonary compliance and resistance during mechanical ventilation: A lung model study. *Pediatric Pulmonology* 22: 35–43.
- Lapinsky SE, Aubin M, Mehta S, Boiteau P, Slutsky AS (1999) Safety and efficacy of a sustained inflation for alveolar recruitment in adults with respiratory failure. *Intensive Care Medicine* 25: 1297–1301.
- Lim C, Jung H, Koh Y, Lee JS, Shim T, Lee S, Kim W-S, Kim DS, Kim W-D (2003) Effect of alveolar recruitment maneuver in early acute respiratory distress syndrome according to antiderecruitment strategy, etiological category of diffuse lung injury, and body position of the patient. *Critical Care Medicine* 31: 411–417.
- Lim C-M, Koh Y, Park W, Chin JY, Shim TS, Lee SD, Kim WS, Kim DS, Kim WD (2001) Mechanistic scheme and effect of 'extended sigh' as a recruitment maneuver in patients with acute respiratory distress syndrome: A preliminary study. *Critical Care Medicine* 29: 1255–1260.
- Lindgren S, Almgren B, Högmán M, Lethvall S, Houltz E, Lundin S, Stenqvist O (2004) Effectiveness and side effects of closed and open suctioning: an experimental evaluation. *Intensive Care Medicine* 31: 1630–1637.
- Lu Q, Capderou A, Cluzel P, Mourgeon E, Abdenour L, Law-Koune JD, Straus C, Grenier P, Zelter M, Roubly JJ (2000) A computed tomographic scan assessment of endotracheal suctioning-induced bronchoconstriction in ventilated sheep. *American Journal of Respiratory and Critical Care Medicine* 162: 1898–1904.
- Maggiore SM, Jonson B, Richard J-C, Jaber S, Lemaire F, Brochard L (2001) Alveolar derecruitment at decremental positive end-expiratory pressure levels in acute lung injury. *American Journal of Respiratory and Critical Care Medicine* 164: 795–801.
- Maggiore SM, Lellouche F, Pigeot J, Taille S, Deye N, Durrmeyer X, Richard J, Mancebo J, Lemaire F, Brochard L (2003) Prevention of endotracheal suctioning-induced alveolar derecruitment in acute lung injury. *American Journal of Respiratory and Critical Care Medicine* 167: 1215–1224.
- Main E, Castle R, Stocks J, James I, Hatch D (2001) The influence of endotracheal tube leak on the assessment of respiratory function in ventilated children. *Intensive Care Medicine* 27: 1788–1797.
- Marcus RJ, Van der Walt JH, Pettifer JA (2002) Pulmonary volume recruitment restores pulmonary compliance and resistance in anaesthetized young children. *Paediatric Anaesthesia* 12: 579–584.
- Marraro GA (2003) Innovative practices of ventilatory support with pediatric patients. *Pediatric Critical Care Medicine* 4: 8–20.
- Matthews BD, Noviski N (2001) Management of oxygenation in pediatric acute hypoxemic respiratory failure. *Pediatric Pulmonology* 32: 459–470.
- Morrow B, Futter M, Argent A (2006) Effect of endotracheal suction on lung dynamics in mechanically-ventilated paediatric patients. *Australian Journal of Physiotherapy* 52: 121–126.
- Neumann P, Berglund JE, Mondéjar EF, Magnussen A, Hedenstierna G (1998) Dynamics of lung collapse and rerecruitment during prolonged breathing in porcine lung injury. *Journal of Applied Physiology* 85: 1533–1543.
- Pelosi P, D'Onofrio D, Chiumello D, Paolo S, Chiara G, Capelozzi VL, Barbas CS, Chiaranda M, Gattinoni L (2003) Pulmonary and extrapulmonary acute respiratory distress syndrome are different. *European Respiratory Journal* 42: Suppl. Aug; 48s–56s.
- Polacek L, Guthrie MM (1981) The effect of suction catheter size and suction flow rate on negative airway pressure and its relationship to the fall in arterial oxygen tension. *American Journal of Respiratory and Critical Care Medicine* 123: S120.
- Richards G, White H, Hopley M (2001) Rapid reduction of oxygenation index by employment of a recruitment technique in patients with severe ARDS. *Journal of Intensive Care Medicine* 16: 193–199.
- Rimensberger PC, Cox PN, Frndova H, Bryan AC (1999) The open lung during small tidal volume ventilation: Concepts of recruitment and 'optimal' positive end-expiratory pressure. *Critical Care Medicine* 27: 1946–1952.
- Russell FE, Van der Walt JH, Jacob J, Slater AJ, Baghurst P (2002) Pulmonary volume recruitment manoeuvre restores pulmonary compliance and resistance after apnoea in anaesthetized lambs. *Paediatric Anaesthesia* 12: 499–506.
- Shann F (1998) Drug Doses (10th edn.) USA: Collective.
- Suh GY, Koh Y, Chung MP, An CH, Kim H, Jang WH, Han J, Kwon OJ (2002) Repeated derecruitments accentuate lung injury during mechanical ventilation. *Critical Care Medicine* 30: 1848–1853.
- Taskar V, John J, Evander E, Robertson B, Jonson B (1997) Surfactant dysfunction makes lungs vulnerable to repetitive collapse and reexpansion. *American Journal of Critical Care Medicine* 155: 313–320.
- Tusman G, Böhm SH, Tempira A, Melkun F, García E, Turchetto E, Mulder PGH, Lachmann B (2003) Effects of recruitment maneuver on atelectasis in anesthetized children. *Anesthesiology* 98: 14–22.
- Van der Kloot TE, Blanch L, AM Youngblood, Weinert C, Adams AB, Marini JJ, Shapiro RS, Nahum A (2000) Recruitment maneuvers in three experimental models of acute lung injury. Effect on lung volume and gas exchange. *American Journal of Respiratory and Critical Care Medicine* 161: 1485–1494.
- Villagrà A, Ochagavía A, Vatua S, Murias G, Fernández M, Aguilar JL, Blanch L (2002) Recruitment maneuvers during lung protective ventilation in acute respiratory distress syndrome. *American Journal of Respiratory and Critical Care Medicine* 165: 165–170.
- Young CS (1984) Recommended guide lines for suction. *Physiotherapy* 70: 106–108.